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BASIC ENGINEERING CRITERIA AND COST ESTIMATIONS FOR HYBRID MICROBIAL FILTER-REED (*Phragmites communis*) WASTEWATER TREATMENT CONCEPT

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16. ABSTRACT

An advanced wastewater treatment process has been developed through a joint NASA-EPA program which combines microbial filter technology with vascular plant wastewater treatment technology. This wastewater treatment system consists of two components: a sludge collection and digestion chamber and a hybrid microbial filter-vascular plant unit. The design criteria for each component is discussed. The basic design parameters and cost estimations for this concept used to meet the wastewater treatment needs of a community of 3,000 are outlined.

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INTRODUCTION

Man, like all other animals, depends upon a symbiotic relationship between green plants and microorganisms for his existence on earth. Photosynthesizing plants produce and regulate the oxygen required to support life, in addition to utilizing and controlling the concentration of carbon dioxide and other gaseous chemicals produced by man, animals, and microorganisms during their metabolic processes. Plants, in conjunction with microorganisms, also recycle man's waste and produce his food. These fundamental facts have been known and taken for granted by man for hundreds of years. What man has not known, but is beginning to realize, is that natural biological processes involving the symbiotic relationship between certain plants and microorganisms can also be used to correct environmental imbalances caused by waste disposal, industrial development, and environmental abuse, if carefully manipulated (1-4). The harnessing of natural biological processes is essential for man's future health and economical growth.

Surface water contamination from accidents and improperly treated domestic and industrial waste discharged into major river systems has been a problem in the U. S. for many years. In addition, the disposal of hazardous chemical waste by deep-well injection and improper landfill operations in the United States is slowly contaminating ground water supplies from which a large part of the population receive their drinking water.

WASTEWATER TREATMENT PROCESSES

Wastewater treatment processes can be divided into three types: physical, chemical, and biological.

Physical processes involve removing solid materials. These processes include screens, commutators for grinding solids, and grit chambers and clarifiers which are settling tanks for the removal of settleable solids.

Chemical treatment processes involve addition of chemicals to expedite wastewater treatment while increasing the cost substantially in most cases. Examples of chemicals used in wastewater treatment are alum for coagulation and precipitation, acids or bases for pH adjustment, and chlorine for disinfection, ammonia removal, etc.

Biological processes use microbial action to degrade and stabilize colloidal and dissolved organic materials from wastewater. If this material is not stabilized before it enters receiving rivers and streams, the dissolved oxygen can be depleted due to aerobic microorganisms metabolizing organics and oxidizing nutrients which are in a reduced state. This biochemical oxygen demand (BOD), if too great, can remove large quantities of oxygen from the water causing fish and other aquatic life to leave the area or die from "suffocation" or oxygen starvation.

There are two classes of biological treatment: aerobic and anaerobic.

Aerobic biological treatment processes utilize microorganisms requiring free oxygen to metabolize the organic material in wastewater. Aerobic processes include trickling filters, activated sludge processes, rotating biological contractor filters, oxidation ditches and aerobic lagoons. The aerobic microorganisms in these processes decompose the organic material to make carbon dioxide and water and produce large volumes of biologically active sludge.

Anaerobic biological treatment processes utilize microorganisms which live in the absence of free oxygen and utilize chemically bound oxygen to metabolize organic material. Anaerobic processes include anaerobic digestors, anaerobic lagoons, and anaerobic filters. Anaerobic processes utilize two groups of microorganisms. The first group transforms the colloidal and dissolved organic material to volatile organic acids. The second group converts the organic acids to methane gas and carbon dioxide with traces of odorus sulfides. Anaerobic microorganisms have relatively slow growth rates and produce much less sludge than the aerobic processes. The sludge from anaerobic processes is also stabilized.

Facultative biological treatment processes utilize both aerobic and anaerobic microorganisms in separate zones. A facultative lagoon is an example of this process and is very popular in small cities.

Theoretically, the facultative lagoon is ideally suited for wastewater treatment because the bottom portion of the lagoon is anaerobic where the sludge accumulates and is stabilized through anaerobic digestion, while the volume is significantly decreased. The facultative middle zone continues the wastewater treatment while the algae-laden, oxygen-rich upper aerobic zone finishes the treatment process by oxidizing the odorous sulfides producing an odor-free, clarified wastewater effluent.

Unfortunately this process does not stay balanced, especially during the warm summer months when uncontrolled algal growth occurs. Practical, economical means of harvesting algae have not been developed to prevent large algal blooms from dying and decaying in the lagoon, causing excess BOD loading, foul odors and increased total suspended solids.

Presently, aerobic processes are used almost exclusively in the United States. The activated sludge process is generally used for large cities, while the trickling filter process is more popular for small cities. The least expensive systems are lagoons which depend on algae to supply oxygen photosynthetically. The other aerobic processes require much more initial investment to design and construct, besides high operational cost due to increased personnel and energy needs.

NASA/NSTL'S RESEARCH CONTRIBUTIONS TO THE DEVELOPMENT OF NEW, COST-EFFECTIVE WASTEWATER TREATMENT PROCESSES

During the past eight years, NASA has conducted research at the National Space Technology Laboratories (NSTL) in Mississippi on the utilization of vascular plants to replace algae in natural biological processes for the efficient and economical treatment of domestic and chemical wastewater generated at NSTL (5-10). The vascular aquatic plants used in the first studies were floating species. The two major species were the water hyacinth *(Eichhornia crassipes)* and duckweed *(Lemna* sp. and *Spirodela* sp.). This research was highly successful and led to the installation of simple, cost-effective wastewater treatment systems at NSTL. Communities and cities in Florida, Texas and California are also using floating aquatic plants for wastewater treatment. Engineering design data for this type wastewater treatment system was published (5, 11).

Recently an advanced natural wastewater treatment process has been developed through a joint NASA-EPA program which combines microbial filter technology with the vascular plant wastewater treatment technology to produce an efficient hybrid system (2, 12). This system uses rooted, cold-tolerant plants such as the common reed *(Phragmites communis)* growing on the surface of a microbial rock filter bed. The microbial filter-reed system has advantages over the floating aquatic plant systems in that wastewater is only exposed to the atmosphere after treatment, reducing the risk of odor problems, allowing the system to be installed in highly populated areas. Higher chemical concentrations in wastewater can be tolerated because a higher microbial cell density is sustained and partially retained on the surface of the filter. The system can be used in colder climates when installed below the frost line, and estaurine environments with higher salt concentrations because of the salt- and cold-tolerant characteristics of reeds. The high microbial cell density in the filter unit also increases the potential for adding industrial waste to domestic sewage without upsetting the microbial process.

DESIGN CRITERIA OF THE HYBRID MICROBIAL FILTER-VASCULAR PLANT WASTEWATER TREATMENT SYSTEM

This wastewater treatment system is made up of two major components: component one is a sludge collecting and digesting chamber which may consist of a simple septic tank, a covered anaerobic lagoon or a high surface area anaerobic digestor. Component two is a hybrid microbial filter-vascular plant unit. Rocks are used for the microbial filter with pea gravel or sand spread several inches deep on top as a surface sealer. Vascular plants such as the common reed *(Phragmites communis)* are planted on the filter bed. This filter corresponds to the facultative and aerobic section of a facultative lagoon and is capable of treating both aerobic and anaerobic wastewater after sludge removal to prevent filter clogging. The filter depth is critical for removal of both ammonia and nitrate nitrogen during final wastewater treatment and clarification. A depth of approximately two feet or less is desirable since both ammonia and nitrate nitrogen are rapidly removed from a rock-reed filter of this depth. This indicates that the plant roots are contributing sufficient oxygen to the liquid to enhance nitrification, but not enough to sustain this zone in a complete aerobic state. Therefore, conditions conducive to both nitrification and anoxic denitrification prevail in the rock-reed filter.

In order to minimize sludge handling problems, deep anaerobic lagoons, approximately 3 m (10 ft) in depth with small surface areas, appear to be the most practical method for the initial sewage treatment and sludge collection. For single homes or small facilities, septic tanks can be used instead of lagoons. To prevent odor emissions from the anaerobic lagoons, it is essential that the lagoons be sealed or mechanically aerated on the surface. Reinforced, floating hyplon covers with gas collecting capabilities appear to be the most reliable means of assuring complete odor control. This means of odor control is preferable when the system is to be installed in a highly populated area. Methane can be collected and burned as an energy source or the gases flared for odor control. Small systems do not require gas collecting capabilities.

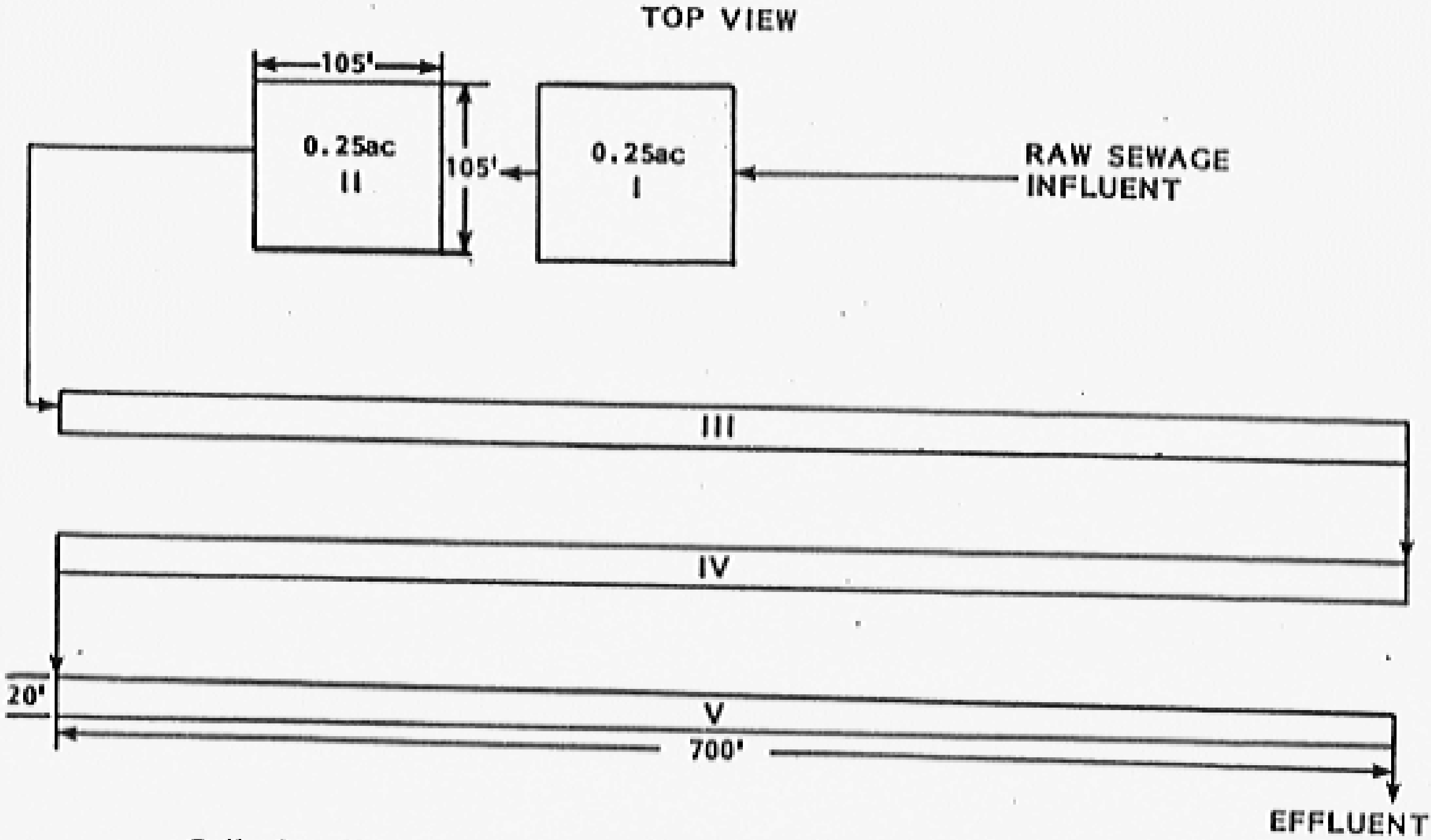
Approximately 114 g (0.24 lb) of sludge per person is generated daily in domestic sewage. When digested anaerobically, the total mass of settleable solids in sewage can be reduced by 50% and removed as gas and soluble substances (13). Approximately 28.3 ℓ (1 cu ft) of methane per person per day can be produced by anaerobically digesting domestic sludge. Yearly sludge accumulation per person after anaerobic digestion is approximately 23 kg (51 lb) or 26.5 ℓ (7 gal) in volume.

The proposed design for a community of 3,000 in Figure 1 allows for approximately 20 years of operation before a sludge removal problem develops in Lagoon No. 1. Lagoon No. 2 can then be used for collecting raw sewage until sludge is removed from Lagoon No. 1. Two lagoons in series with a minimum detention time of 2.5 days each are recommended for a 50% or greater reduction of BOD_5 and total suspended solids, while lowering the risk of sludge reaching and clogging the rock filters (14).

Oswald et al. observed BOD_5 reductions in excess of 70% at hydraulic detention times of 1.5 days in anaerobic lagoons (14). Detention periods of up to five days were recommended to compensate for decreased bacterial activity during cold weather. This reduced bacterial action is less important when a high surface area microbial filter is used for further treatment of the anaerobic lagoon effluent.

Data from a hybrid microbial reed/rock filter using three different BOD_5 loading levels and two different total suspended solids (TSS) concentrations are given in Figures 2 and 3. The initial sewage used in these three experiments was the effluent from closed anaerobic plastic drums in which raw sewage was allowed to settle for 24 hours. The microbial/reed filter unit consisted of a metal trough filled to a depth of 16 cm with railroad rocks 2.5-7.5 cm in diameter and to a depth of 5 cm with pea gravel 0.25-1.3 cm in diameter. The trough, which measured 50.5 cm W x 30.5 cm D x 298 cm L, was planted with reed *(Phragmites communis)*.

If one assumes a 50% or greater BOD_5 and TSS removal in the initial anaerobic lagoon treatment step, then a doubling of the initial BOD_5 and TSS loading rates from Figures 2 and 3 can be used for designing a complete system starting with raw sewage. When anaerobic lagoons or other anaerobic systems are used for the initial treatment step, nitrates are normally removed or converted to ammonia before reaching the microbial reed/rock filter. When the filter unit is used to upgrade trickling filter plants or



Cells I & II: 10' deep, covered anaerobic lagoons

Cells III, IV, & V: 2' deep canals filled with rock, sealed with pea gravel, and planted with reed

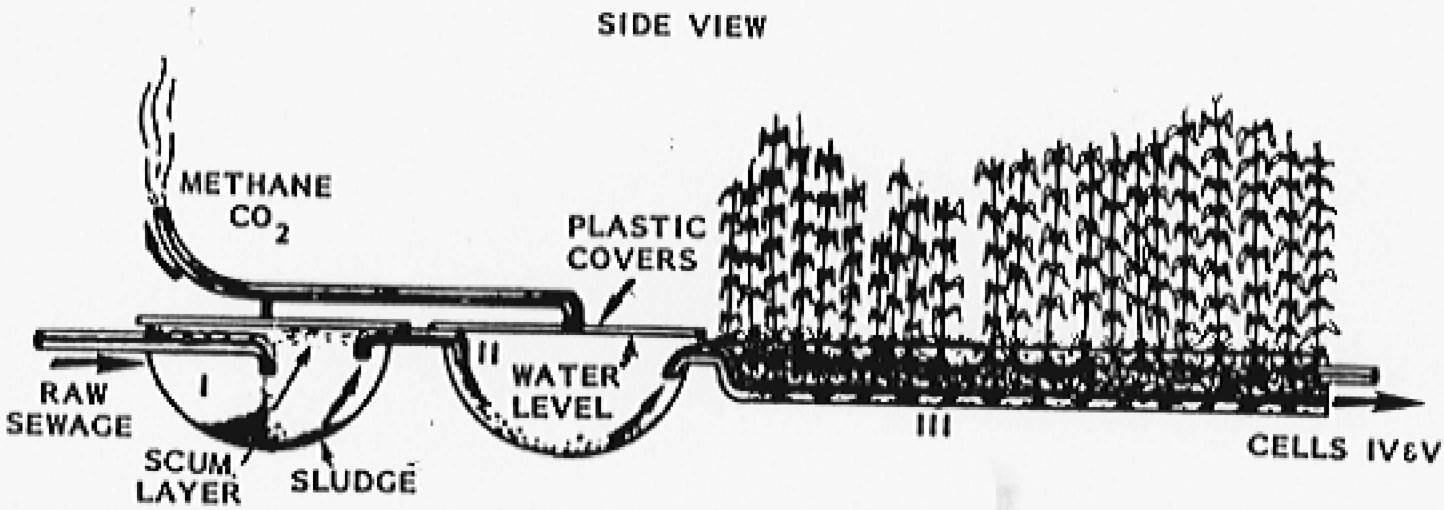


Figure 1. Wastewater treatment facility overview for a community of 3,000 based on anaerobic filter and vascular aquatic plant technology.

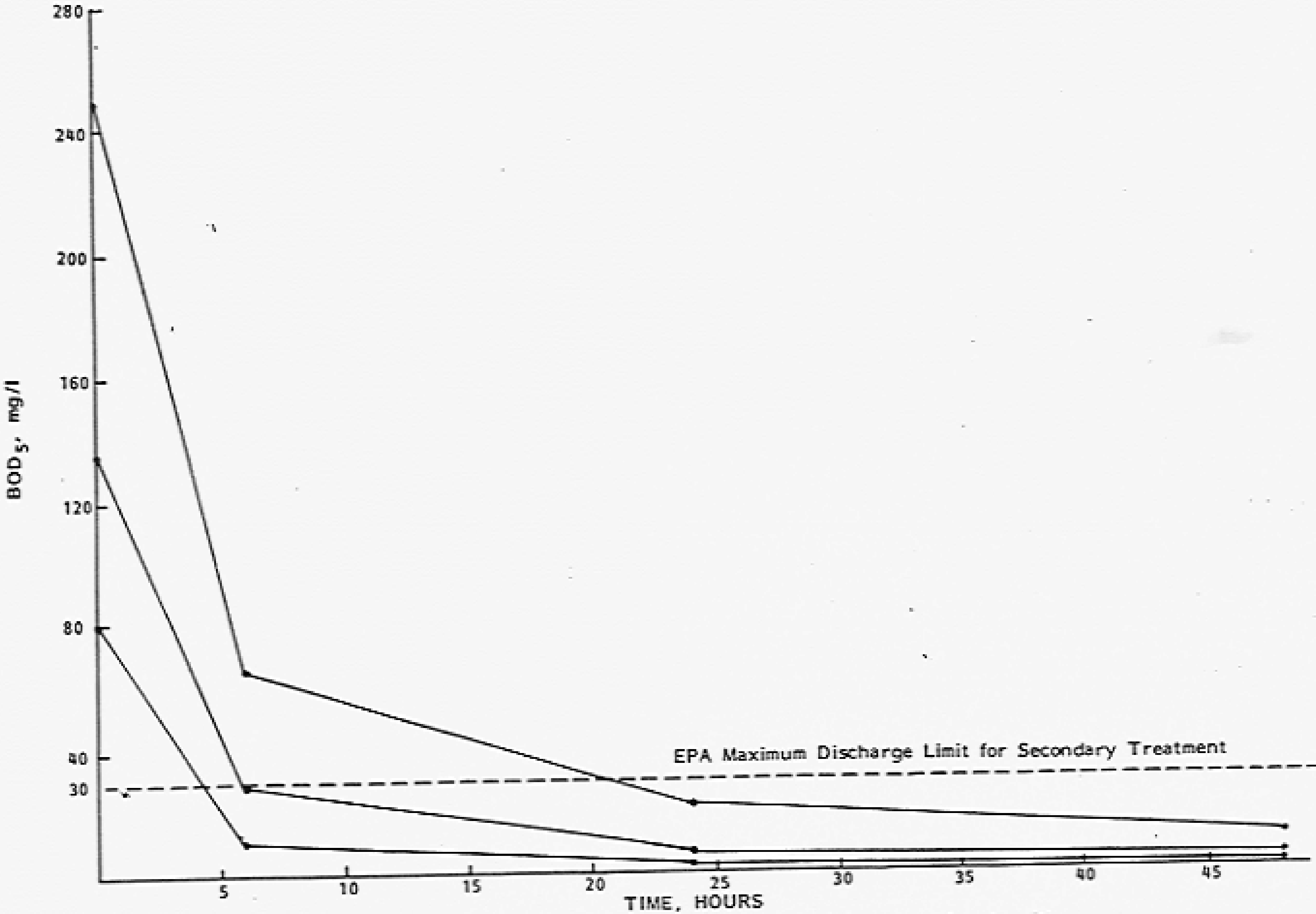


Figure 2. Each curve represents the average of four experiments with similar initial BOD$_5$'s. The sewage was treated for 24 hours in anaerobic settling tanks. The initial BOD$_5$'s were obtained on the effluent from the settling tank during transfer to the microbial/reed rock filters (av. temp. 23°C).

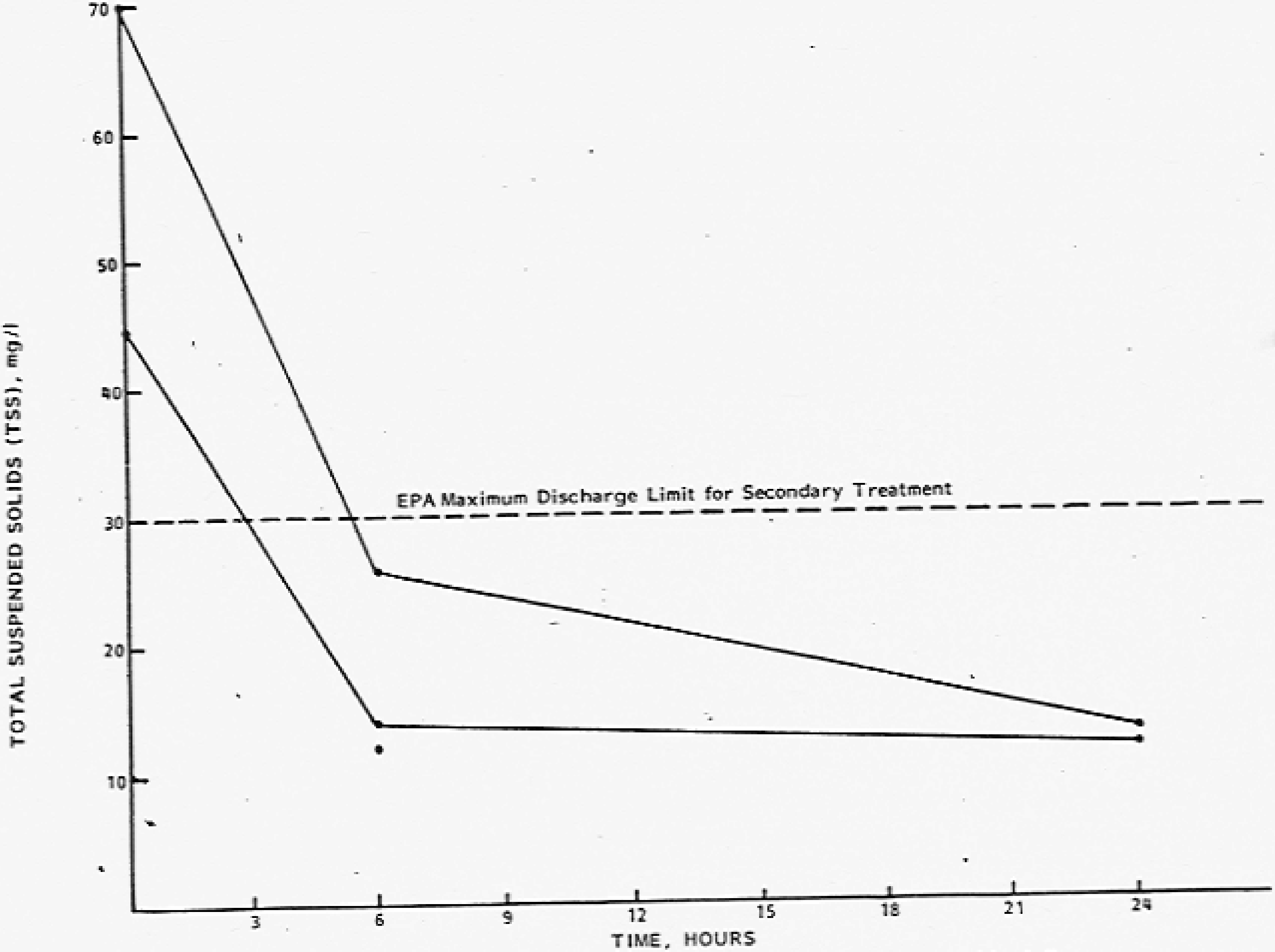


Figure 3 Each curve represents the average of four experiments with similar initial TSS's. The sewage was treated for 24 hours in anaerobic settling tanks. The initial TSS's were obtained on the effluent from the settling tanks during transfer to the microbial/reed rock filters (av. temp. 23°C).

other aerobic wastewater effluent, nitrates present in the effluent will also be removed. The capacity of this filter system to remove nitrates and ammonia is demonstrated in Figure 4. Although the proposed design in Figure 1 is for a complete new wastewater treatment system for a community of 3,000, the 0.41 ha (1 ac) microbial reed/rock filter alone can be used to upgrade trickling filter or activated sludge plants treating approximately one million gallons per day (wastewater from a population of 10,000). The cost can be estimated by extracting only the construction cost of the microbial/reed filter in Appendix 1. Figures 2, 3, and 4 can be used to determine exact detention times depending on the treatment efficiency of the existing facility and the maximum discharge concentrations permitted by state and Federal regulations.

Appendix 1 contains a gross cost estimate for a system based on NASA's technology to serve a community of 3,000. The configuration was previously given in Figure 1.

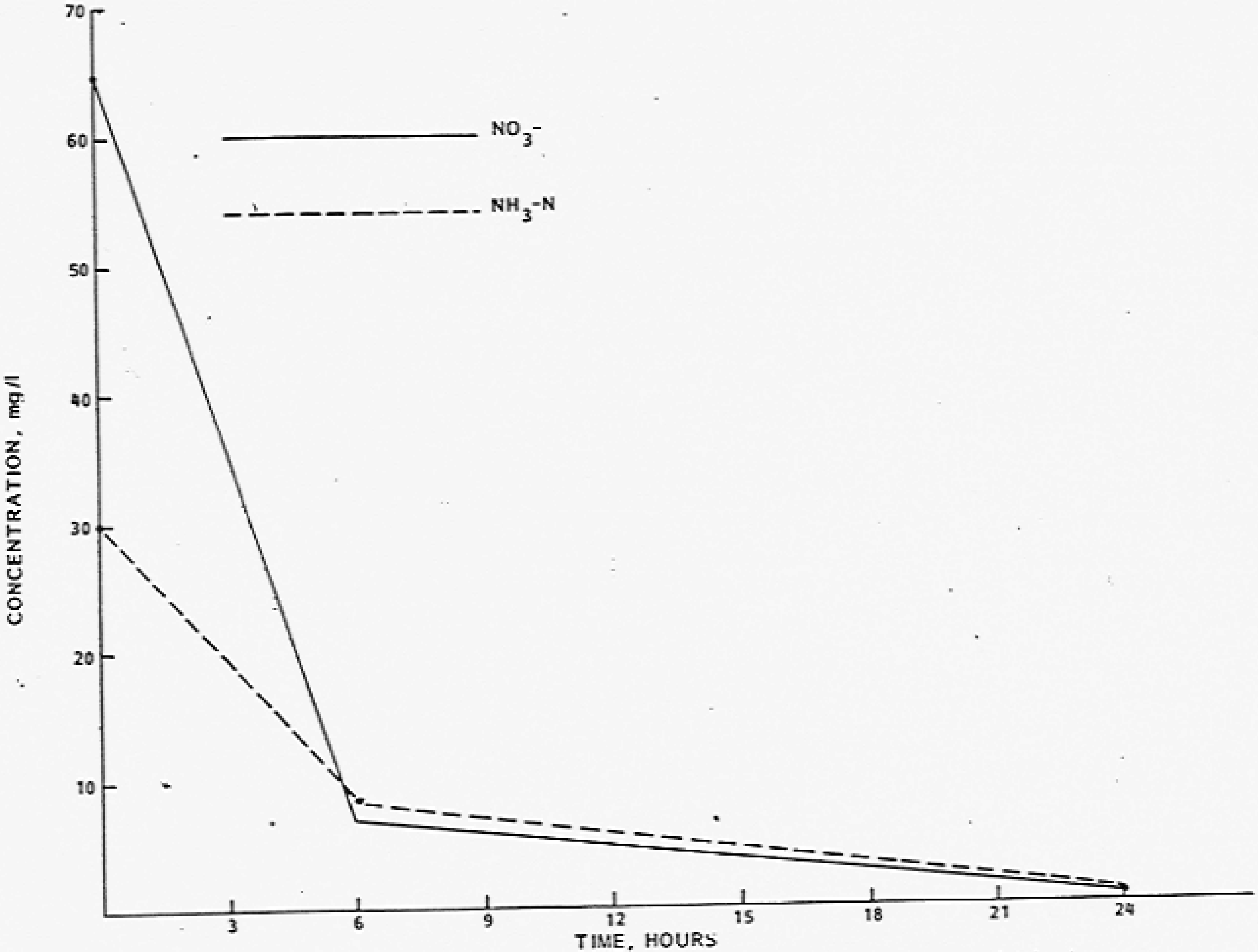


Figure 4 Average data from 8 experiments in which sewage was detained for 24 hours in an anaerobic settling tank, then spiked with ammonia nitrate and treated in a microbial/reed rock filter for 24 hours (av. temp. 23°C).

LITERATURE CITED

1. Duffer, W. R. and J. E. Moyer. 1978. Municipal wastewater aquaculture. U.S.E.P.A. 600/2-78-110.

2. Wolverton, B. C. 1982. Hybrid Wastewater Treatment System Using Anaerobic Microorganisms and Reed (Phragmites communis). Econ. Bot. 36(4) 373-380.

3. Wolverton, B. C. and Rebecca C. McDonald. 1982. The Role of Vascular Aquatic Plants in Wastewater Treatment. The Herbarist. 48:24-29.

4. Wolverton, B. C. and Rebecca C. McDonald. 1981. Natural Processes for Treatment of Organic Chemical Waste. The Env. Professional. 3:99-104.

5. Wolverton, B. C. 1979. Engineering Design Data for Vascular Aquatic Plant Wastewater Treatment Systems. Aquaculture Systems for Wastewater Treatment. EPA 430/9 80-006. 179-182.

6. Wolverton, B. C. and Rebecca McDonald. 1979. The Water Hyacinth: From Prolific Pest to Potential Provider, AMBIO, 8(1): 1-9.

7. Wolverton, B. C. and Rebecca McDonald. 1979. Upgrading Facultative Wastewater Lagoons with Vascular Aquatic Plants. Journal Water Pollution Control Federation, 51(2): 305-313.

8. Wolverton, B. C. and Rebecca McDonald. 1977. Wastewater Treatment Utilizing Water Hyacinths. Proceedings of the 1977 Natl. Conf. on Treatment and Disposal of Ind. Wastewater and Residue, Univ. Houston, Texas, 205-208.

9. Wolverton, B. C., R. M. Barlow and R. C. McDonald. 1976. Application of Vascular Aquatic Plants for Pollution Removal, Energy and Food Production In: Tourbier, J. and R. W. Pierson, Jr. (Eds). Biological Control of Water Pollution, Univ. of PA. Press, Philadelphia, PA., 141-149.

10. McDonald, R. C. and B. C. Wolverton. 1980. Comparative Study of Wastewater Lagoon With and Without Water Hyacinth. Econ. Bot. 34(2): 101-110.

11. Gee and Jenson Engineers. 1980. Water Hyacinth Wastewater Treatment Design Manual. Gee and Jenson, West Palm Beach, Florida. 92 pp.

12. Wolverton, B. C., R. C. McDonald and W. R. Duffer. 1982. Microorganisms and Higher Plants for Wastewater Treatment. Submitted to: Journal Env. Quality.

13. Metcalf & Eddy, Inc. 1979. Wastewater Engineering: Treatment/Disposal/Reuse. 2nd Ed. McGraw-Hill Book Co., New York, N. Y.

14. Oswald, W. J., C. G. Golueke and R. W. Tyler. 1967. Integrated Pond Systems for Subdivisions. Journal Water Pollution Control Federation, 39(8): 1289.

APPENDIX 1

COST ESTIMATE FOR 1140 m^3/d (0.3 MGD) ANAEROBIC LAGOON MICROBIAL FILTER/REED WASTEWATER TREATMENT SYSTEM*

1. CONSTRUCTION COST FOR TWO 3050 m^3 (805,860 gal) CAPACITY ANAEROBIC LAGOONS

Quantity	Item	Cost
6167 m^3 (8,066 yd^3)	Excavation of two 0.25 acre anaerobic lagoons - \$1.31/m^3 (\$1.00/yd^3)	\$ 8,066.00
0.41 ha (1.0 ac)	Land - \$12,000/ha (\$5,000/ac)	5,000.00
15.2 m (50 ft)	PVC connecting pipe - installed \$65.80/m (\$20.00/ft)	1,000.00
2787 m^2 (30,000 ft^2)	**20 mil PVC liner for anaerobic lagoons \$2.69/m^2 (\$0.25/ft^2) installed	7,500.00
2023 m^2 (21,780 ft^2)	**36 mil reinforced floating hyplon covers \$10.76/m^2 (\$1.00/ft^2) installed	21,780.00
	SUB-TOTAL	\$43,346.00

2. CONSTRUCTION COST FOR MICROBIAL/REED FILTER

Quantity	Item	Cost
91.4 m^3 (3,228 yd^3)	Excavation of one acre of rock filters \$1.31/m^3 (\$1.00/yd^3)	\$ 3,228.00
61 m (200 ft)	**PVC connecting pipe and header pipe to distribute the flow entering each channel - installed \$41.00/m (\$12.50/ft)	2,500.00
4047 m^2 (43,560 ft^2)	**20 mil PVC liner for rock filters \$2.69/m^2 (\$0.25/ft^2) installed	10,890.00
91.4 m^3 (3,228 yd^3)	Rocks - \$10.46/m^3 (\$8.00/yd^3)	25,824.00
11.3 m^3 (400 yd^3)	Pea gravel - \$7.84/m^3 (\$6.00/yd^3)	2,400.00
43,560 ea	Reeds planted - \$0.10 ea	4,356.00
0.83 ha (2 ac)	Land - \$12,000/ha (\$5,000/ac)	10,000.00
	SUB-TOTAL	\$59,198.00

I. Total Cost for Complete PVC-Lined System	I. TOTAL	\$102,544.00
II. Total Cost for Complete System Where Natural Clay Barrier is Used (PVC Liner Not Required)	II. TOTAL	\$84,154.00

* Excluding clearing of land, harvester, contingencies, engineering design and/or site evaluation.

** PVC and Hyplon Liner Cost (1982) from Staff Industries, Inc. 713/266-2620 Houston, Texas

APPROVAL

ENGINEERING DESIGN AND COST DATA FOR HYBRID MICROBIAL FILTER-REED (*Phragmites communis*) WASTEWATER TREATMENT SYSTEM

by B. C. Wolverton, Ph.D. and Rebecca C. McDonald

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Energy Research and Development Administration programs has been made by the NSTL Security Classification Officer. This report in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

A. M. Payne
Manager, Installation Operations